

# Heavy Quark Measurements by Single Electrons in the PHENIX Experiment

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**Abstract.** Transverse momentum ( $p_T$ ) distribution of electrons for  $0.3 < p_T < 9.0$  GeV/ $c$  have been measured in midrapidity ( $|\eta| < 0.35$ ) in Au + Au collisions and  $p + p$  collisions at  $\sqrt{s_{NN}} = 200$  GeV by the RHIC-PHENIX experiment. Two methods for background subtraction were applied to determine the electron yield from open charm and bottom decays. The nuclear modification factor was calculated, and significant suppression at high- $p_T$  was observed in Au + Au collisions, indicating substantial energy loss of heavy quarks in the dense medium.

## 1. Introduction

Heavy quark (charm and bottom) measurement is important to extend our knowledge of underlying QCD properties. Its measurement in  $p + p$  collisions at RHIC serves as a good test of QCD. Bottom productions at the Tevatron and HERA are well described by next-to-leading order (NLO) perturbative QCD calculations [1]. RHIC data will also help our theoretical understanding of the production and fragmentation mechanism of heavy quarks, especially, charm. In Au + Au collisions at RHIC, strong suppressions of light flavor mesons at high transverse momentum ( $p_T$ ) have been observed [2, 3, 4]. The suppressions are due to significant energy loss of partons through an extremely dense matter, not conventional hadronic matter. Due to the large mass, heavy quark can interact with the dense medium in different ways from light partons. The measurement will provide significant and complementary information of mechanism of parton energy loss.

## 2. Experiment and Analysis

The PHENIX experiment took high statistic data at  $\sqrt{s_{NN}} = 200$  GeV in Run-4 Au + Au collisions (2004) [5] and in Run-5  $p + p$  collisions (2005) [6]. Electrons ( $e^+/e^-$ ) in

\* For the full PHENIX Collaboration author list and acknowledgments, see appendix ‘Collaborations’ of this volume.

$0.3 < p_T < 9.0$  GeV/ $c$  were detected by two PHENIX central arms, each covering azimuthal angle  $\Delta\phi = \pi/2$  and pseudo-rapidity  $|\Delta\eta| < 0.35$  [7].

All measured electrons can be categorized into two groups. The first group consists of “*photonic*” electrons which mainly come from Dalitz decays of mesons ( $\pi^0, \eta$ , etc.) and photon conversion. The second group is termed as “*non-photonic*” electrons in which open charm/bottom decays are dominant sources. We applied two methods, “*cocktail*” and “*converter*” methods to extract non-photonic electrons by subtracting photonic electrons from all electrons [5, 6]. The both methods give the consistent result. Cocktail method is effective to count signal electrons at high- $p_T$ , where the signal to background ratio is large. Converter method has small systematic error by the direct measurement of photonic electron components, but the statistical error is dominated by the statistics of converter-installed runs. Almost all the non-photonic electrons are produced from semileptonic decays of open charms and bottoms. Backgrounds in the non-photonic electrons come from mainly weak decays of Kaon ( $K_{e3}$ ) and di-electron decays (vector meson decays and Drell-Yan process). Kaon contributes  $< 10\%$  at  $p_T = 0.5$  GeV/ $c$  compared to photonic electron yields, while vector mesons are very small, and Drell-Yan process is negligible in our measurable  $p_T$  range. Since Kaon and vector mesons have been already measured by the PHENIX, backgrounds from those sources can be evaluated with simulations and subtracted from non-photonic electrons.

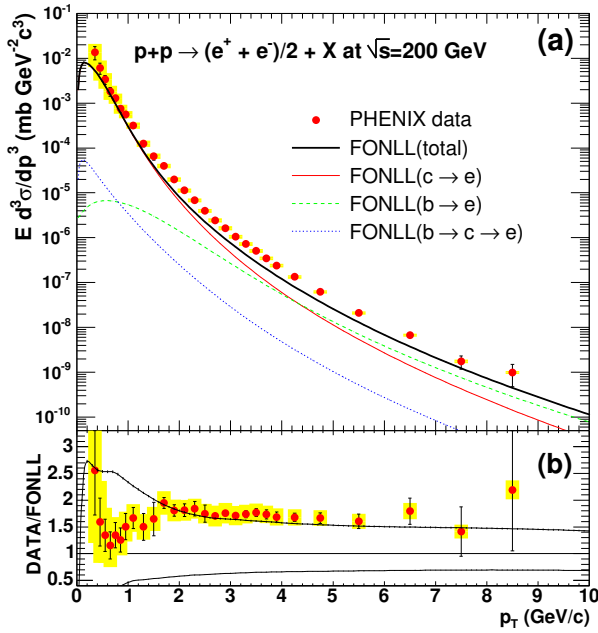
### 3. Results

Figure 1 (a) shows the invariant differential cross section of electrons from heavy flavor decays [5]. The data are compared with a fixed-order-plus-next-to-leading-log (FONLL) pQCD calculation [8]. In Fig. 1 (b), the ratio of data to the FONLL is shown ( $1.71 \pm 0.02^{\text{stat}} \pm 0.18^{\text{sys}}$ ). The upper limit of the FONLL calculation is compatible with the data. Total charm cross section is derived by integrating the heavy-flavor electron cross section for  $p_T > 0.4$  GeV/ $c$ :  $d\sigma/dy = 5.95 \pm 0.59^{\text{stat}} \pm 2.0^{\text{sys}} \mu\text{b}$ .

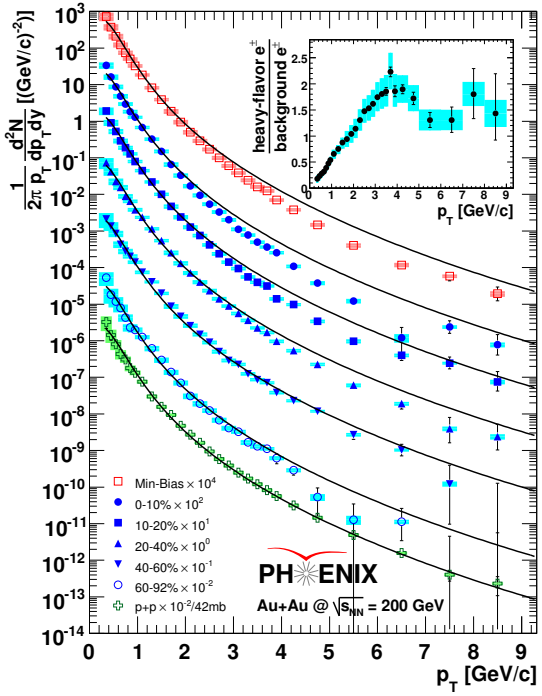
Figure 2 shows invariant differential yields of electrons from heavy flavor decays for each centrality-class in Au + Au collisions [5]. To quantify the suppression, the nuclear modification factor,  $R_{\text{AuAu}}(p_T)$  was calculated:

$$R_{\text{AuAu}}(p_T) = \frac{dN^{\text{AuAu}}/dp_T}{\langle T_{\text{AuAu}} \rangle d\sigma_{\text{in}}^{pp}/dp_T} = \frac{dN^{\text{AuAu}}/p_T}{N_{\text{col}} dN^{pp}/dp_T}. \quad (1)$$

Here,  $\sigma_{\text{in}}^{pp}$  is the inelastic scattering cross section of  $p + p$ ,  $\langle T_{\text{AuAu}} \rangle$  is the nuclear thickness function for Au + Au and  $N_{\text{col}} = \langle T_{\text{AuAu}} \rangle \cdot \sigma_{\text{in}}^{pp}$ .  $R_{\text{AuAu}}(p_T)$  for each centrality-class is shown in Fig. 3. Very strong suppression is clearly seen at high- $p_T$  from the most central to the mid central collisions, comparable to the suppression observed for  $\pi^0$  and  $\eta$  [2, 4]. Figure 4 shows  $R_{\text{AuAu}}$  as a function of the number of participant ( $N_{\text{part}}$ ). For  $p_T > 0, 3$  GeV/ $c$ ,  $R_{\text{AuAu}}$  is close to unity for all  $N_{\text{part}}$ , which indicates binary scaling of the total heavy-flavor yield works. For  $p_T > 3$  GeV/ $c$ , the  $R_{\text{AuAu}}$  decreases systematically with  $N_{\text{part}}$ .



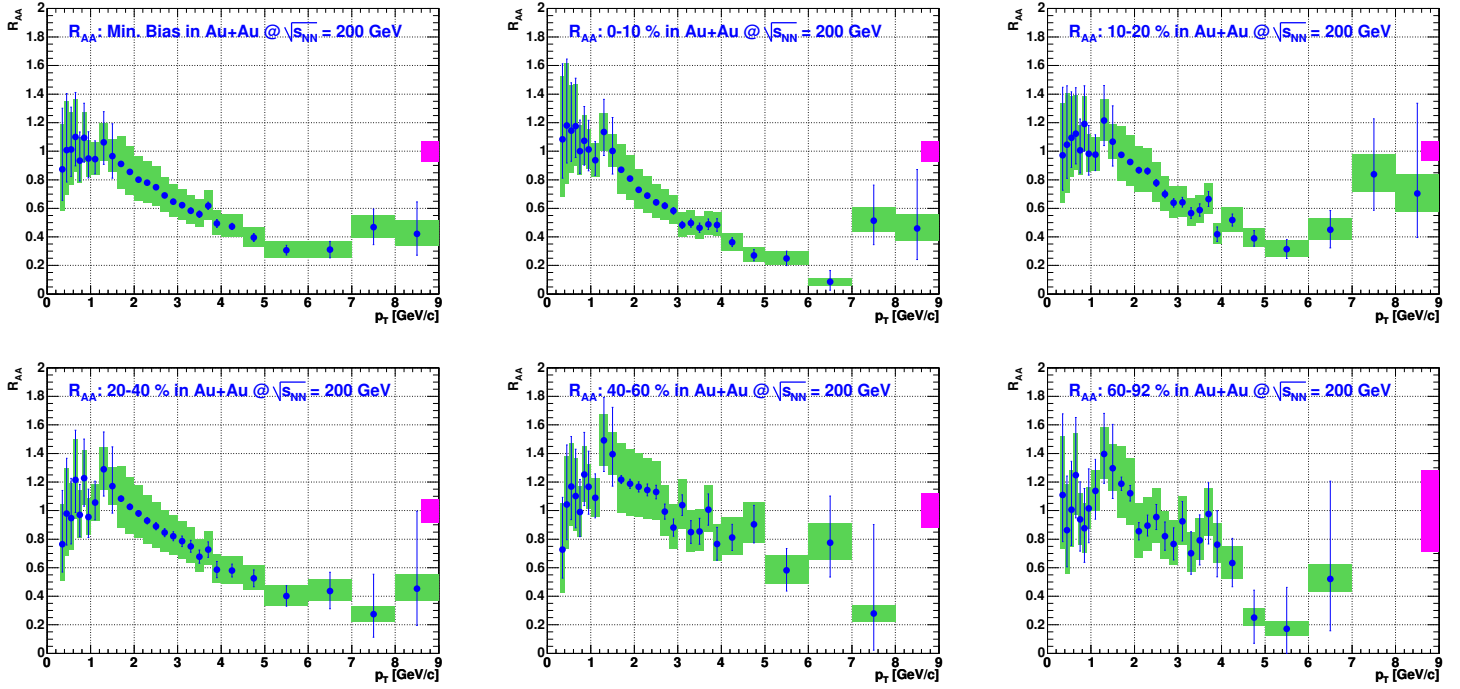
**Figure 1.** (a) Invariant differential cross sections of electrons from semileptonic decays of heavy quarks in Run-5  $p + p$  collisions. The error bars (bands) represent the statistical (systematic) errors. The curve are the FONLL calculations. (b) Ratio of the data and the FONLL calculation. The upper (lower) curve shows the theoretical upper (lower) limit of FONLL calculation.



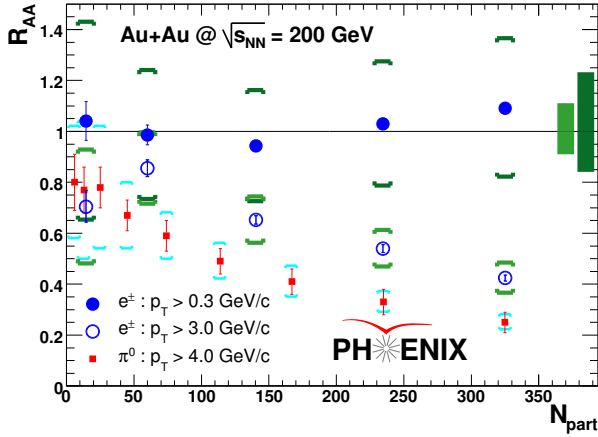
**Figure 2.** Invariant differential yields of electrons from semileptonic decays of heavy quarks in Run-5  $p + p$  and Run-4  $Au + Au$  collisions for each centrality-class, scaled by power of ten for clarity. The solid lines are the result of the FONLL calculation normalized ( $\times 1.71$ ) to the  $p + p$  data and scaled with  $\langle T_{AuAu} \rangle$  for each  $Au + Au$  data. The inserted box shows the signal/background ratio of electrons for minimum bias events in  $Au + Au$  collisions. Error bars (boxes) depict statistical (systematic) uncertainties.

#### 4. Summary and Outlook

The PHENIX has measured electrons from semileptonic decays of heavy quarks in RHIC Run-4  $Au + Au$  and Run-5  $p + p$  collisions at  $\sqrt{s_{NN}} = 200$  GeV. The FONLL calculation agrees with  $p + p$  data within the theoretical and experimental uncertainties. The nuclear modification factor ( $R_{AuAu}$ ) shows a very strong suppressive effect. The result suggests that even heavy quarks lose their energy in high dense medium. To understand it systematically, we need to separate the contributions from charm or bottom in the future experiment. The mass difference will provide us the more information of the energy-loss mechanism in the high dense matter.



**Figure 3.**  $R_{\text{AuAu}}$  of heavy-flavor electrons as a function of  $p_T$  in each centrality class (minimum bias, 0-10 %, 10-20 %, 20-40 %, 40-60 %, and 60-92 %). The error bars (boxes) depict point-by-point (scaling) uncertainties of combined statistical and systematic errors, derived from Au + Au and  $p + p$  data. The box around  $R_{\text{AuAu}} = 1$  in the right side shows the uncertainty of  $\langle T_{\text{AuAu}} \rangle$ .



**Figure 4.**  $R_{\text{AuAu}}$  of heavy-flavor electrons with  $p_T$  above 0.3 and 3.0 GeV/c. and of  $\pi^0$  with  $p_T > 4$  GeV/c as a function of  $N_{\text{part}}$ . Error bars (brackets) depict statistical (point-by-point) and systematic uncertainties. The right (left) box error around  $R_{\text{AuAu}} = 1$  in the right side shows the relative uncertainty from the  $p + p$  data common to the all points except for  $\pi^0$  data.

## References

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